Military Performance and Health Monitoring in Extreme Environments

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ABSTRACT

The Netherlands Defence Organization aims at an optimal deployment of their personnel. However, during missions such as in Afghanistan soldiers encounter adverse and extreme environments and have to sustain their performance for several days, sometimes approaching or exceeding the limits of their capabilities and health. Therefore, in 2008 a 4-year Defense Research Program was initiated on 'Military Performance and Health Monitoring'. This program aims at developing knowledge on physical and cognitive sustainability during military operations in extreme environments. In return this knowledge will be used to develop (real-time) performance and health monitoring systems for individual operational readiness. To judge individual operational readiness, commanders merely have to rely on subjective observations. Technological developments enable (real-time) assessment of the physical and cognitive state of individual soldiers under operational circumstances. To define and predict individual readiness, commanders can benefit from decision support tools. Knowledge from NATO HFM-132 (RTG) was used to define and develop a mobile field lab to assess physiological and cognitive performance during military operations. Combined with environmental data and observational measures, this field lab has been applied to gather data during training courses for the Air Mobile Brigade and the Marines. These data and data from future investigations will be used to build a multi-parameter model for predicting operational readiness. This model will serve as the basis for the commander support tool. Furthermore research will be done on new ambulatory measurement techniques as well as the validation of applied methods using gold standards and laboratory research. Other topics covered in this research program are; the data-processing, the user interface, and the presentation of information to the user. The research program will also address issues as operational feasibility, ethical considerations and opportunities for performance and/or health enhancing interventions. The research program will deliver several results. The field lab will be fine tuned and optimized for operational research. Based on the combination of current knowledge/models and data gathered from the field trials, a multi-parameter model will be developed to predict operational readiness in soldiers during sustained operations. Furthermore demonstrators for (real-time) performance and health monitoring will be developed.

1 INTRODUCTION

The Netherlands Defence Organization aims at an optimal deployment of their personnel. Warfighters have to perform under stressful circumstances and thus should be both physically and mentally fit to meet operational demands. During missions such as in Afghanistan soldiers encounter adverse and extreme environments and have to sustain their performance for several days, sometimes approaching or exceeding the limits of their capabilities and health. To address issues such as operational readiness, performance optimization, personal performance and health monitoring a 4-year Defence Research Program was

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14. ABSTRACT

The Netherlands Defence Organization aims at an optimal deployment of their personnel. However, during missions such as in Afghanistan soldiers encounter adverse and extreme environments and have to sustain their performance for several days, sometimes approaching or exceeding the limits of their capabilities and health. Therefore, in 2008 a 4-year Defense Research Program was initiated on Military Performance and Health Monitoring. This program aims at developing knowledge on physical and cognitive sustainability during military operations in extreme environments. In return this knowledge will be used to develop (real-time) performance and health monitoring systems for individual operational readiness. To judge individual operational readiness, commanders merely have to rely on subjective observations. Technological developments enable (real-time) assessment of the physical and cognitive state of individual soldiers under operational circumstances. To define and predict individual readiness, commanders can benefit from decision support tools. Knowledge from NATO HFM-132 (RTG) was used to define and develop a mobile field lab to assess physiological and cognitive performance during military operations. Combined with environmental data and observational measures, this field lab has been applied to gather data during training courses for the Air Mobile Brigade and the Marines. These data and data from future investigations will be used to build a multi-parameter model for predicting operational readiness. This model will serve as the basis for the commander support tool. Furthermore research will be done on new ambulatory measurement techniques as well as the validation of applied methods using gold standards and laboratory research. Other topics covered in this research program are; the data-processing, the user interface, and the presentation of information to the user. The research program will also address issues as operational feasibility, ethical considerations and opportunities for performance and/or health enhancing interventions. The research program will deliver several results. The field lab will be fine tuned and optimized for operational research. Based on the combination of current knowledge/models and data gathered from the field trials, a multi-parameter model will be developed to predict operational readiness in soldiers during sustained operations. Furthermore demonstrators for (real-time) performance and health monitoring will be developed.

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initiated in 2008. This program, called ‘Military Performance and Health Monitoring’, aims at developing knowledge on physical and cognitive sustainability during military operations in extreme environments. In return this knowledge will be used to develop (real-time) performance and health monitoring systems for individual operational readiness.

Monitoring and predicting soldiers’ performance is becoming more and more important. To do so, it is indispensable not only to monitor the outcome or the result but also the individual and his environment (Figure 1).

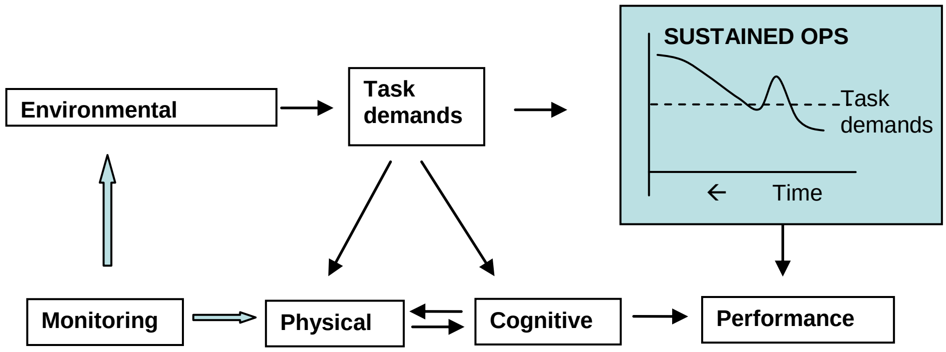

Figure 1: Research program scheme: monitoring environment, individual physical and cognitive functioning, and performance outcome.

Monitoring systems to be developed not only enable the Defence Organization to improve military performance; they also may guard the health and safety of its personnel. In operational settings where extreme environments are playing a significant role, monitoring systems may have added value.

A NATO working group (HFM-RTG 132) has addressed the issues of real-time physiological and psycho-physiological status monitoring for human protection and operational health applications. The current research program is building on the knowledge from this working group and takes into account the recommendations for future research:

- focus more attention on providing the commander with information regarding warfighters’ readiness to fight based on real-time continuous ambulatory physiological and psycho-physiological measurements
- establish practical test-bed venues, such as those offered by military training sites, to develop, acquire, test, and validate (new) ambulatory physiological monitoring sensor systems
- ensure that comprehensive data sets are collected that can be used for predictive modelling
- establish databases that can be used to develop and test new predictive algorithms
- validate new algorithms against new data sets collected during rigorous training missions in different environments

It is important to define relevant performance and health measures and to investigate what are the most adequate parameters to monitor and predict military performance. Today’s knowledge is limited and merely focussed on single physiological signals such as heart rate, respiration rate, core temperature, skin temperature and body movements. There is a lack of adequate classification methods and no multi-parameter models exist that combine these signals in a reliable and valid way. The interaction between physical and cognitive task demands and the effect of physical load on cognitive performance play an important role in operational settings but are not or poorly addressed in these models. Furthermore, knowledge on the effects of sustained operations, the effects of prolonged exposure to extreme environments and changing physical and mental task demands is limited.

Central issues for the research program are:

- the effects of ambient stressors, such as energy expenditure, climate, mountainous terrain, and sleep and circadian factors
- monitoring methods and available models
- monitoring systems and development of field labs
- data handling, algorithms and multi-parameter model
- development of a user interface

2 AMBIENT STRESSORS, MONITORING METHODS AND MODELS

Warfighters are engaged in highly enduring missions, as they are operating in enemy terrain in isolation. Their operational performance is the outcome of a wide spectrum of (inter-) related factors including motivation, equipment, tactics, preparation, mental and physical capabilities, terrain, and environmental conditions, such as altitude and temperature. Insufficient sleep, nutrition, and physiological coping capabilities may become the limiting factors for successful accomplishment of sustained missions. Therefore, these factors have to be taken into consideration when planning and executing missions. Monitoring sleep, alertness, energy balance, thermal balance, and environment-related physiological processes of crew engaged in heavy training and/or sustained combat operations can provide essential data that enable developing strategies to increase resilience and prevent unacceptable impairment of performance during sustained operations.

2.1 Energy expenditure

While energy intake is usually determined by the distributed food rations, several parameters have to be used to measure energy expenditure. The total energy expenditure can be divided into three major components [1]:

- resting metabolic rate (RMR) = basal metabolic rate (BMR) = resting energy expenditure (REE)
- thermic effect of food (TEF) = dietary induced thermogenesis (DIT)
- Thermic effect of activity (TEA) = thermic effect of exercise (TEE). TEA can be sub-divided into thermic effects of volitional exercise (sports, etc) and non-exercise activity thermogenesis (NEAT; activity of daily living).

The addition of RMR, TEF, and TEA normally accounts for 100 percent of total energy expenditure. However, there is a variety of factors that may increase energy expenditure above normal, such as cold, fear, stress, and various medications or drugs. The thermic effect of these factors is referred to as adaptive thermogenesis, which may be an important factor to consider in the case of warfighter sustained operations. For determination of the total energy expenditure one needs to have the values of RMR, TEF, and TEA and one has to take the adaptive thermogenesis into consideration.

2.1.1 Energy expenditure: field monitoring methods and models

Several methods are available for monitoring energy expenditure. Under laboratory conditions direct and indirect calorimetry can be used, but these methods are impossible to use under field conditions. The doubly labelled water (DLW) technique has been validated as the gold standard method for determining free-living total daily energy expenditure [2]. Main disadvantages of this method are that it is expensive because of the use of isotopes and that it requires frequent urine collection. Although it can be used under field conditions, the DLW method is not practical for every-day monitoring during military missions. It is however recommended to use this method to evaluate simpler methods that may be used in the field.

For predicting RMR several mathematical formulas are available. In 2004, USARIEM (United States Army Research Institute of Environmental Medicine) has evaluated several formulas and concluded that the Schofield Equations were to be preferred to estimate RMR of the warfighter [3]:

Men: $RMRs = 0.627BW + 28.82$
Women: $RMRs = 0.617BW + 20.26$

in which RMR is in kilocalories/hour and BW stands for Body Weight (Schofield, 1985).

RMR can also be determined under field circumstances using hand-held indirect calorimetry devices like the BodyGem, MedGem (www.microlife.com), or FitMate (www.fitmate.net). The BodyGem uses sensors to measure relative humidity, temperature, and barometric pressure for use in internal calculations that derive RMR. Oxygen concentration in the inspired and expired airflow is measured by a sensor. RMR is calculated from oxygen consumption and a fixed respiratory quotient (RQ) of 0.85 using a modified de Weir equation [4]. The BodyGem measures RMR in 12 minutes and has been validated against oxygen consumption measured with a metabolic cart or a Douglas bag [5].

Estimations or indirect calorimetry devices only provide values for RMR. To estimate the total daily energy expenditure, one also needs to know the energy expenditure due to physical activity. Subjective measures include direct observation of physical activity by a trained observer, or recording of daily physical activities by the subject itself. Both methods seem less feasible to use for routine monitoring during missions because it either requires the presence of a researcher, or it requires training of the subject since each activity needs to be quantified as to time, intensity, and type of activity. Furthermore, the input data and the calculation of total energy expenditure should be conducted by trained researchers (Chen, 2003).

Indirect objective measures use some type of mechanical or electronic device (e.g., pedometers, heel- or foot-strike monitors, accelerometers, heart-rate monitors, heat-flow sensors) to measure changes in body movement, heart rate or body temperature. The data acquired from these devices are integrated with personal data (e.g., age, weight, stride length, gender) and integrated into a formula that predicts energy expenditure. Multidimensional devices that include multiple types of metabolic measurements are better at predicting energy expenditure than methods addressing a single variable. Advanced pattern recognition and automated classification modelling techniques, such as artificial neural networks that can incorporate multiple input parameters and output feedbacks for nonlinear and adaptive modelling, need to be explored [6].

One of the major threats encountered by warfighters is dehydration (and overhydration) and it is important to develop a reliable and simple method to monitor the hydration status in the field. Assessment of serum osmolality is considered as the gold standard, however this method needs collection of blood. Monitoring water intake by instrumentation of the drink bottles or camel bag, has to be matched with fluid loss in order to be effective as an estimator for hydration status. This method is laborious and not practical during labor intensive missions.

Measurement of urine specific gravity in the field is feasible (dip-stick), or individuals could be trained to associate a urine specific gravity that represents dehydration with the colour of their urine [7]. Being able to field-monitor fluctuations in body weight would also be an excellent indicator of hydration status, since short-term changes in body weight are directly attributable to changes in body water volume. However, carrying a pair of scales for everyday weighting is not considered feasible for warfighters during a mission. In summary, no good method to monitor hydration status is currently available, and there is a strong need for a good non-invasive system to reliably indicate acute changes in hydration status.

2.2 Climate

The human thermal balance is determined by climate, clothing, exercise intensity and individual factors such as acclimatization status. The human body reacts to thermal stressors and this is called thermal strain.

Thermal strain is an important parameter in soldier performance. In the heat, soldiers may become exhausted so that direct activities have to be stopped. The number of heat stroke victims is increasing in the last years in the US armed forces [8]. Similar problems occur in the cold, where the number of local cold injuries may rise to about 5% during operations of Marines in cold areas [9].

2.2.1 Climate: field monitoring methods and models

The physical parameters related to climate are 1) ambient temperature, 2) wind speed, 3) relative humidity, 4) precipitation, 5) (solar) radiation and 6) altitude (barometric pressure). Ambient temperature can be measured using thermometers. Both thermocouples and thermistors are available in small sizes and can be attached to data loggers to measure ambient temperature over time. Some systems have integrated sensors and loggers in one small housing, e.g. Ibuttons (www.ibuttons.com). Ambient temperature can also be measured using simple stickers, indicators on paper (http://www.palmerwahl.com/temp-plate-temperature-recording-labels.php). It is important that thermometers are shielded for radiation and wind to give a true temperature reading. At high ambient temperatures, in particular in combination with solar radiation, objects may become warmer than 43ºC and skin burns may occur. Stickers may be glued to objects that may become hot to give a timely warning. Similarly, frostnip may occur when touching cold objects and temperature stickers may warn the soldier in time. Skin burns and frostbite are not uncommon during special operations and reduce the sustainability. Wind takes away the air layer around the skin that constitutes the interface between skin temperature and ambient temperature. In the heat, wind reduces thermal strain; in the cold thermal strain is increased. Wind can be laminar and turbulent. Laminar flow can be measured using a propeller, in which the number of revolutions is related to wind speed. The laminar wind speed is higher when measured further from the ground level. Turbulent wind is more difficult to measure, but an indication can be derived from the temperature difference between a hot wire in and out the wind. Other anemometer (=wind meter) types include ultrasonic or laser anemometers that detect the phase shifting of sound or coherent light reflected from the air molecules.

High relative humidity hampers the evaporation of sweat and thus reduces human cooling capacity. Relative humidity can be measured with electronic devices. Accuracy of small, low cost devices is in the range of about 5% (e.g. www.ibutton.com). (Solar) radiation is absorbed by the human skin and increases the body temperature. In the cold, radiation reduces heat strain and in warm circumstances heat strain is increased. Solar radiation can be measured using the temperature difference between a black bulb thermometer and a thermometer shielded from radiation, but can also be measured electronically: photodiodes are inexpensive and accurate.

Several attempts have been made to include the physical climatic parameters in one single climatic index. The combination of ambient temperature and wind speed is called wind chill. Wind chill is related to the risk of freezing of the exposed skin and to manual dexterity decrease [10]. The soldier in the field may use available wind chill charts to estimate the risk for freezing skin.

The combination of ambient temperature and relative humidity is called the heat index (HI) in the US and the humidex in Canada. Both the HI and humidex can be supplied in charts with risk indicators.

The most frequently used climatic index is the Wet Bulb Globe Temperature (WBGT). The Wet Bulb Globe Temperature (WBGT) is a composite temperature used to estimate the effect of temperature, humidity, and solar radiation on humans. It is used to determine appropriate exposure levels to high temperatures:

$$WBGT = 0.7Tw + 0.2Tg + 0.1Td$$

where Tw= Natural wet-bulb temperature (humidity indicator); Tg=Globe thermometer temperature (solar radiation measured with a black globe thermometer); and Td=Dry-bulb temperature (normal air temperature).

Important parameters to evaluate thermal strain are: body core temperature, mean skin temperature, heart rate and sweat loss. Thermal pills are easy to use in the field and results are comparable to esophageal temperature, generally considered as the gold standard [11]. Main systems on the market are: the coretemp system (www.hqinc.net) and the vital sense and mini-logger of the mini-mitter company (http://www.bio-lynx.com/MINI-MITTER.htm). Lutz and Coker developed a heat strain indicator based on tympanic temperature with a warning system when the core temperature exceeded a certain preset value [12]. Quest currently manufactures such a system (http://www.quest-technologies.com /Heat/QTII.htm). Skin temperature can be measured using thermocouples or thermistors. For long term measurements without immediate feedback, ibuttons are recommended [13]. Based on core and skin temperatures one may calculate the body heat gain. A body heat gain of over 10 J/g body weight is generally considered as a limit for heat related problems.
Sweat loss is easy to measure using a weighing scale before and after the task. Subjects should be measured (semi) nude and the clothing should be weighed separately. The weight increase of the clothing should be subtracted from the weight loss of the subject to calculate the cooling power of the evaporated sweat. Sweat dripping off the body should also be estimated and subtracted from the body weight loss. The contents of sweat also reflects thermal strain: the electrolyte loss per liter of sweat increases with thermal strain.

Sometimes thermal strain is combined with thermal stress indicators, in order to make an individual recommendation for performance limits [14]. Until now, however, the proposed indices are hardly used in military practice due to their complexity. The US 6th Ranger Training Battalion evaluated a device to calculate the personal heat strain index with good reviews, but "there's no strong Army proponent for fielding it right now" (see http://www.natick.army.mil/ about/pao/2002/02-30.htm).

2.3 Mountainous terrain

Rapid deployment of unacclimatized military personnel to altitudes above 5000 ft (1524 m) may cause debilitating effects on operational capabilities (physical and cognitive work performance), and force health (altitude sickness). Troops operating in mountainous environments are exposed to hypobaric hypoxia, which triggers a series of integrated physiologic changes. These changes function to increase oxygen supply to body tissues and are most noticeable in those body systems that are directly related to oxygen delivery (i.e. respiratory and cardiovascular), but changes occur in all organ systems. Over time, the series of changes produce a state of physiologic adaptation (“acclimatization”), which allows soldiers to achieve the maximum work performance possible for the altitude to which they are acclimatized.

2.3.1 Mountainous terrain: field monitoring methods and models

In order to determine the work capacity, resilience, and the capacities for further ascent to higher altitudes, it is useful to be able to determine the effects of hypoxia and the level of acclimatization. In that context, the following methods are recommended to use during sustained SF operations in mountainous areas:

At high altitudes, peripheral SaO2 (haemoglobin-oxygen saturation) measured by pulse-oximetry should preferably use the ear lobe or reflection methods (e.g. forehead), as fingers may be unsuitable due to hypoxia-induced peripheral vasoconstriction and cold. To predict the physical work capacity (and thus force power) at altitude, the SaO2 and maximal heart rate (HRmax) can be used as easy-to-apply methods [15]. The difference between SaO2 at sea level and SaO2 at actual altitude, measured during (sub)maximal exercise, is considered as the most useful indicator of physical work capacity. Also differences in HRmax can be used, albeit that literature data of HRmax are less consistent than for SaO2.

Work capacity and the level of acclimatization are closely related. With a cut-off value of 81.5%, resting SaO2 at 4200 m is a useful predictor of the level of acclimatization and AMS risk (pos. predictive value: 0.81; neg. predictive value: 0.67). During ascents from 1200-4300 m, SaO2 measured at the end of 50 m walking has been shown to be a better predictor for developing AMS than resting SaO2 alone. Although a precise cut-off value is not defined, measurement of SaO2 during sleep (nocturnal hypoxemia) may have useful additive value in monitoring AMS risk. Pulse oximetry may also be useful to assess hyperventilatory capacity (HVC), which is considered to be a predictor for AMS risk.

ΔHRmax (difference sea level – actual altitude) during (sub)maximal exercise is considered as a useful additive indicator of physical work capacity (in combination with ΔSaO2). Resting pulse rate is a weak predictor of the level of acclimatization, but can be used in combination with SaO2. A subject can be considered to be acclimatized to an altitude when SaO2 and HR show stable levels on that altitude over several days. Heart rate variability (HRV) characteristics, preferably measured during sleep, may be useful to monitor acclimatization.

As sleep is often fragmented at high altitude and quality of sleep is an important determinant of daytime performance, monitoring of sleep is recommended by using actography in combination with subjective sleep diaries. Actigraphy data may combined with pulse oximetry (desaturation during apnea/hypopnea events) to determine periodic breathing as a cause of sleep fragmentation.

To monitor subjective ratings of AMS symptoms the Lake Louise-self-report score (LL-self) is indispensable to monitor AMS risk and it can be used in combination with physiological measurements [16]. The LL-self can be performed on a PDA or handheld computer and subjects can be given feed-back of their score with a warning to report their symptoms when the LL-self score is ≥3.

Models should be developed to predict physical and mental work capacity of warfighters engaged in mountainous operations. Recommended factors to be used in such models are the effects of hypoxia and acclimatization on SaO2, Heart Rate, and vigilance performance. It is recommendable to consider extension of the SCOPE model with a high altitude module using these factors [17]. The SCOPE model already has a module concerning sleep deprivation, which can be further developed to include the disturbing effects of altitude on sleep in the prediction of work capacity.

To predict the probability of AMS, a model as developed by Vann et al. may be used, although application of existing guidelines, such as provided by Muza et al., may be equally useful to minimize AMS risks in soldiers [18, 19].

2.4 Sleep and circadian factors

There is firm evidence that heavy physical exercise, severe mental stress, inadequate sleep facilities, and hostile environmental conditions, such as experienced in sustained operations of warfighters, may lead to significant sleep disturbance and sleep loss [20]. Moreover, crew may be already fatigued at the start of a mission because of the high incidence of sleep problems in out of area military base-camps [21].

Nightly operations require personnel to sleep during the day. The circadian rhythm dictates activity during the day, which causes the quality of daytime sleep to be inferior compared to nighttime sleep [22]. The combination of circadian sleep pressure during the night and inferior daytime sleep causes impaired alertness and performance in night workers. Evidence from large studies of industrial shift workers indicates significant increased risks of errors and accidents during the night shift and in the early morning [23]. Severely fatigued crew often estimate their level of alertness to be higher than it actually is and this may further increase the error and accident risks at night [24].

2.4.1 Sleep and circadian factors: field monitoring methods and models

Sustained operations of warfighters will be vulnerable to the effects of sleep deprivation and circadian disruption. Ensuring sufficient recuperative sleep is an important means to optimize resilience and performance. Therefore, it is recommended to monitor sleep, effects of sleep loss, and circadian disruption of military personnel engaged in heavy training programs or combat activities. To monitor sleep under field conditions, useful markers are subjective and objective (actigraphy) Total Sleep Time (TST) and subjective sleep quality. In addition, it is useful to monitor sleepiness and/or vigilance as markers of the state of fitness of personnel under field conditions. Assessment of performance of a vigilance task is a most sensitive option to monitor effects of sleep deprivation and circadian mismatch.

With regard to monitoring resilience in more detail, assessment of heart rate variability during sleep, as a measure of sympathovagal balance, maybe a feasible method. Determination of blood levels of immunological or hormonal markers is not feasible under field conditions and results of such measurements are difficult to interpret in a practical context.

In the day-to-day practice of monitoring sustained military operations there is no place for Electro-encephalography (EEG), Multiple Sleep Latency Tests (MSLT), Maintenance of Wakefulness Test (MWT), or assessment of Slow Eye Movements (SEM). Research should therefore be aimed to establish robust relationships between these objective measures and simple subjective methods, such as the Karolinska Sleepiness Scale and the Samn-Perelli Fatigue scale.

Models will be useful to enable planning of missions and practical management of sleep-related resilience during training or combat missions. Most models addressing sleep and performance relationships are not developed to predict military performance or resilience. The best option may be to consider the SAFTE, or FAST models because these models have originally been developed for applied research in warfighting [25].

3 MONITORING SYSTEMS AND FIELD LABS

For designing field labs to be used in operational settings we evaluated existing of the shelf products on physiological monitoring and used common well established methods to assess sleep, body weight and fat, cognition, subjective ratings, and weather.

Technological developments more and more enable the real-time assessment of physiological parameters. They are improving in functionality, decreasing in size and becoming feasible for use in military operational settings. For our field trials we tested the Zephyr (www.zephyrtech.co.nz/) and Equivital (www.equivital.co.uk) system in a laboratory setting and compared the signals with gold standards as measured with a Mobi physiological data logger (www.tmsi.com). Although both systems were comparable with respect to data quality and data loss, the Equivital system showed to be most ahead in integrating a core set of physiological signals in one central unit including core temperature (Figure 2).

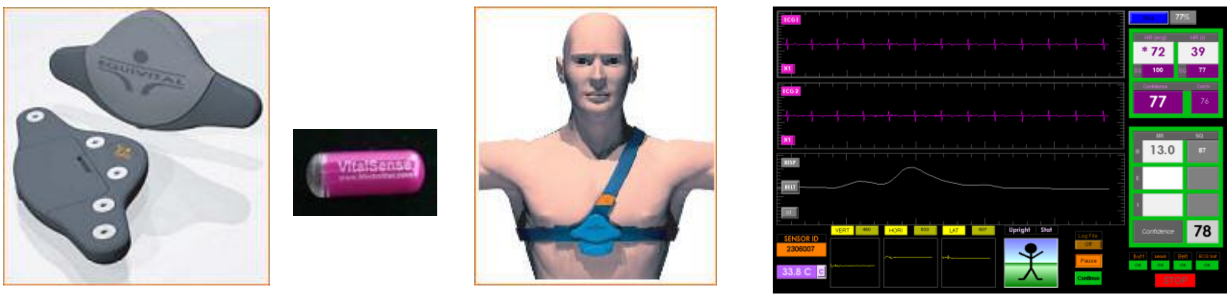

Figure 2: Equivital multi-sensor unit enabling the real-time, parallel and continuous assessment of EKG (and heart rate), respiration (and respiration rate), skin temperature, core temperature (pill), and body movement and position.

To measure the activity level of soldiers, covered walking or running distance and the speed of the movements were recorded. A GPS system (SPi-Elite, GPsports Australia) was mounted on the participant's backpack.

To assess sleep- and activity patterns we applied actigraphy in combination with a subjective sleep record. (Actiwatch: Cambridge Neurotechnology, Cambridge, UK).

To assess cognitive performance, three tasks have been chosen, running on a laptop computer (MSI U100, Taipei Hsien, Taiwan).Working memory was tested using the N-back task [26]. Reasoning and planning was tested using the Tower of Hanoi test (modified version of http://step.psy.cmu.edu/scripts-plus/TOHx).Vigilance was tested using the VigTrack test.. This test is a dual-task measuring vigilance performance under the continuous load of a compensatory tracking task [27].

A Wet Bulb Globe Temperature (WBGT) was used to determine temperature (Celsius), humidity (%) and wind speed (m/s). A weather station (Oregon scientific WMR-200, Oregon Sciencific Inc., Portland, Oregon, USA) was used to measure temperature (Celsius), relative humidity (%), wind speed (m/s), rainfall (mm) and a heat index in case the temperature is higher than 27°C.

Combined with subjective ratings and observational measures, a field lab has been designed and applied to gather data during training courses for the Air Mobile Brigade and the Marines (Figure 3; see papers of Vrijkotte et al. and Veenstra et al. this proceedings). These data and data from future investigations will be used to build a multi-parameter model for predicting operational readiness.

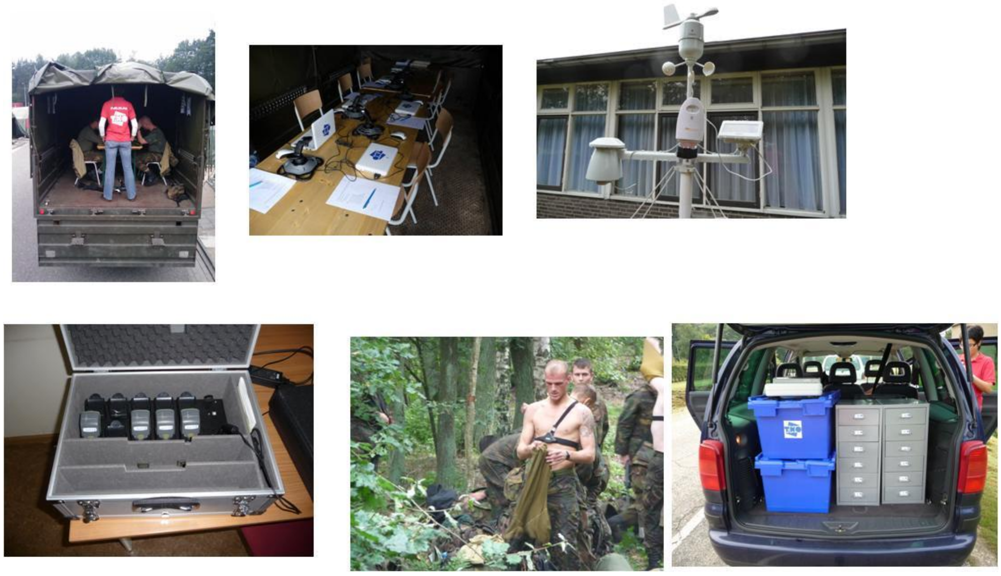

Figure 3: TNO Field Lab

4 DATA HANDLING, DATA MODELLING AND WAY FORWARD

When assessing and predicting operational readiness of warfighters monitoring and data gathering are the basis for the next steps to come. The huge amount of data has to be structured, annotated and should be made accessible. Finally, based on these data, analysis and modelling techniques will be applied to reveal significant factors affecting and influencing military performance in terms of operational readiness and sustainability.

4.1 Data handling

The purpose of the data handling process is to build a so called data-warehouse. This data-warehouse not only enables data storage, but also data management, data accessibility and data analysis. The ware-house will be based on AnySense technology developed by TNO-ICT, and consists of 2 modules: AnySense Connect and AnySense World. The AnySense Connect modules is concerned with gathering and storage of sensor data, while The AnySense World module will transpose the data to comprehensible and contextual information (Figure 4).

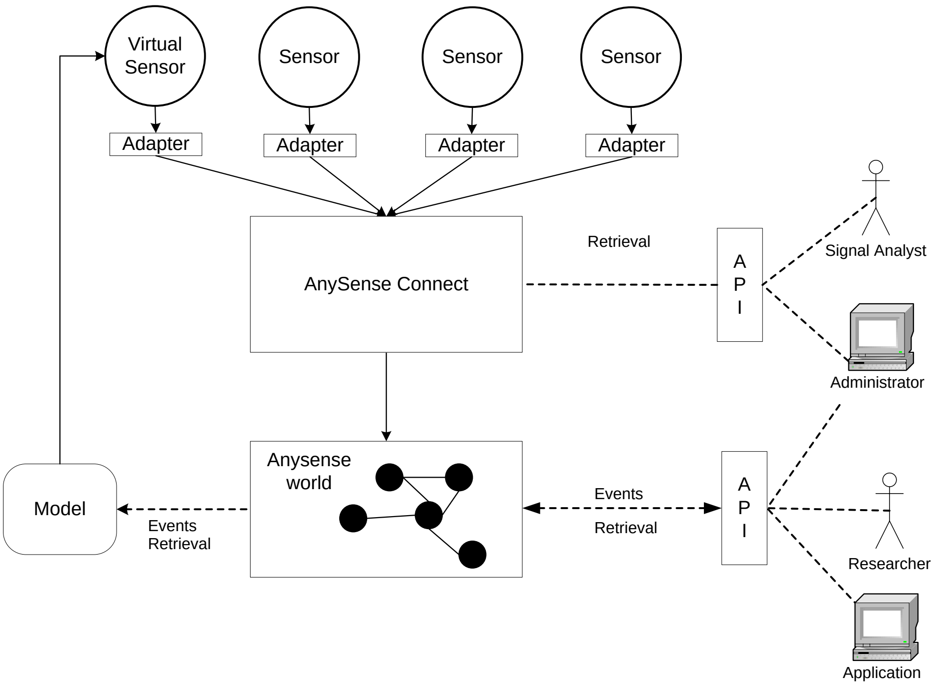

Figure 4: AnySense Connect and AnySense World

4.2 Algorithms and Multi-parameter model

Parallel to the data-handling process a search will be performed for adequate analysis methods to be used for data-mining. Data-mining will reveal patterns and relationships in the huge amount of data. In this way new algorithms can be designed to feed new developed or improve existing performance models. In the end a so-called multi-parameter model will be developed to predict warfighter's individual operational readiness and performance. This model will serve as the basis for operational support tools.

4.3 Way forward

Further research will be performed on new ambulatory measurement techniques as well as the validation of applied methods using gold standards and laboratory research. Other topics covered in this research program are the user interface, and the presentation of information to the user. The research program will also address issues as operational feasibility, ethical considerations and opportunities for performance and/or health enhancing interventions. In the end, the research program will deliver several results. The field lab will be fine tuned and optimized for operational research. Based on the combination of current knowledge/models and data gathered from the field trials, a multi-parameter model will be developed to predict operational readiness in soldiers during sustained operations (Figure 5).

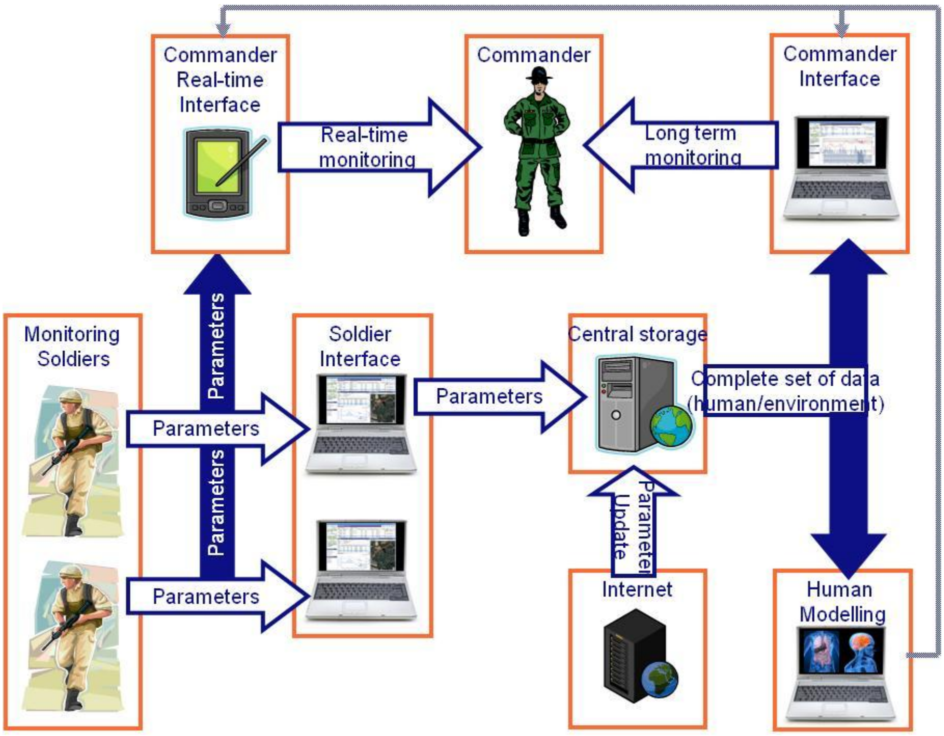

Figure 5: Predicting individual operational readiness

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